ogy over a packet switched network, where certain network nodes take on the master role and other nodes taking on the slave role.

[0018] Nodes taking on the master role (i.e., Master nodes) may typically equipped with a high quality oscillator that allows longer holdover time in case of losing its timing reference from a Primary Reference Clock (PRC) such as global navigation satellite system (GNSS).

[0019] Nodes taking on the Slave role (i.e., Slave nodes) may typically equipped with a lower quality oscillator with a shorter holdover time. For small cell applications where the primary role of a small cell node is for capacity injection instead of coverage, the requirement for the holdover time can be further reduced to, e.g., 30 minutes with a very low cost (and low quality) oscillator.

[0020] Multiple Slave nodes can achieve their timing synchronization with a dedicated Master node via exchanging certain timing packets over the packet switched network. For example, in the IEEE1588v2 standard, a Master node sends regular synchronization message(s) and responds to a Delay_Request message from subordinated Slave nodes to allow Slave nodes to sync up with itself.

[0021] Slave nodes will get into internal free run holdover mode if it loses its synchronization with its dedicated Master node. In the current packet based synchronization design, such as 1588v2 PTP and Network Timing Protocol (NTP), the synchronization distribution is purely a Master-Slave hierarchy without the slave to re-distribute timing among other impacted slaves.

[0022] In a telecommunications network, Slave nodes are typically the base stations that sync up their phase and frequency synchronization with a Master node via the Ethernet or IP packet switched backhaul. If somehow the base station loses its communication with the Master node (typically called a Grand Master Clock), such as when the Master node fails or there is a backhaul outage, it will enter into a holdover period with its oscillator in free run mode providing synchronization for a few minutes/hours/days depending on the quality of oscillator equipped. For example, a Rubidium type of atomic oscillator can provide days of holdover time; a single Oven/Double Oven OXCO (Oven Controlled Crystal Oscillator) typically provides hours of holdover time; and a relatively low cost TCXO (Temperature Compensated Crystal Oscillator) has much lower holdover time.

[0023] After the holdover time elapses, the base station can no longer guarantee phase and frequency synchronization within the radio access network (RAN). As a result, call quality may begin to degrade, inter-base station interference starts to increase, and eventually all calls will be dropped.

[0024] Currently, there is no other way for the Slave node to recover its synchronization except to wait for the communication between itself and its Master node to be recovered or for the Slave node be advised to sync up with another Master node through some predefined Best Master Clock (BMC) algorithm.

[0025] Another problem is the inherent jitter and latency within the packet switched network that can sometimes significantly degrade the phase and frequency synchronization performance on the Slave nodes. In this case, even though Slave nodes can still communicate with the Master node, its degraded synchronization performance will still cause similar problems as a loss of communication with the Master node.

[0026] Therefore, there is a need for techniques to allow Slave nodes to take on a more proactive role to dynamically re-distribute timing and synchronization among themselves in cases of loss of communication with Master nodes or when they determine that the synchronization performance has degraded below a certain threshold due to significant delay and jitter experienced over the packet switched network. This may be of particular importance for small cell/indoor femto cell applications where a cluster of nearby small cells/femto cells typically relies on a single grand master clock (GMC) for synchronization. However, this is obviously not the only situation that would benefit from embodiments of the present invention.

[0027] Embodiments of the invention provide robust systems and methods that enable Slave nodes to proactively take on the GMC role temporarily in order to extend the holdover time for other slave nodes with inferior oscillator quality (and thus lower holdover time).

[0028] According to one embodiment, each Slave node maintains a list of peer Slave nodes that either share the same Master node or have a certain predefined affinity, and announces its holdover time performance to all other Slave nodes in the peer list.

[0029] In most base station synchronization implementations, GNSS is typically used as the primary reference clock source. When GNSS is in outage, the system may switch to other synchronization sources such as 1588v2 PTP Timing over Packet, SyncE, etc. When all synchronization sources fail, systems will then fall back to a local oscillator to provide holdover. Different qualities of oscillator provide different holdover stability. There are many factors that can determine the quality of an oscillator, such as frequency range, stability (frequency drift vs. temperature), temperature range, ageing stability, etc. Therefore, one example of a certain predefined affinity may be slave nodes that are equipped with the same quality of oscillator weighted by available synchronization sources. A slave with the same quality oscillator can declare itself with superior holdover performance if it has additional synchronization source than its peers. For example, a slave with both 1588v2 PTP and SyncE as synchronization source can declare superior holdover performance than the slave with only the 1588v2 PTP input.

[0030] Then, in an embodiment, when a Slave node determines it has lost its communication with the Master node or the delay and jitter in the communication path with its Master node has degraded beyond a certain threshold, the Slave node may announce to other Slave nodes on its peer list that it intends to take on the mini-Master role for at least its pre-announced holdover time. Other Slave nodes, after receiving such announcements from one or more other associated Slave nodes, may determine whether they wants to synchronize with one mini-Master node or whether they should also take on the mini-Master role and start sending their own announcement to other peer Slave nodes.

[0031] Three network attributes may impact performance in IEEE 1588: packet loss, packet delay, and packet delay variation (PDV). A packet loss is caused when resources in a network element are no longer sufficient for handling all the ingress traffic. Depending on the specific implementation, a network element will start dropping packets beginning with low priority traffic to protect loss of packets at higher priority. However, packet loss is not an issue for IEEE 1588v2 because the clock recovery algorithm suite is leveraging an observation window that may span over several seconds. The times-